

On the status of superheavy dark matter

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Superheavy particles are a natural candidate for the dark matter in the universe and our galaxy, because they are produced generically during inflation in cosmologically interesting amounts. The most attractive model for the origin of superheavy dark matter (SHDM) is gravitational production at the end of inflation. The observed cosmological density of dark matter determines the mass of the SHDM particle as $m_X = (\text{a few}) \times 10^{13}$ GeV, promoting it to a natural candidate for the source of the observed ultra-high energy cosmic rays (UHECR). After a review of the theoretical aspects of SHDM, we up-date its predictions for UHECR observations: no GZK cutoff, flat energy spectrum with $dN/dE \approx 1/E^{1.9}$, photon dominance and galactic anisotropy. We analyze the existing data and conclude that SHDM as explanation for the observed UHECRs is at present disfavored but not yet excluded. We calculate the anisotropy relevant for future Auger observations that should be the conclusive test for this model. Finally, we emphasize that negative results of searches for SHDM in UHECR do not disfavor SHDM as a dark matter candidate. Therefore, UHECRs produced by SHDM decays and with the signatures as described should be searched for in the future as subdominant effect.

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I. INTRODUCTION

Superheavy Dark Matter (SHDM) is an interesting aspect of modern particle physics and cosmology. Being first suggested as explanation [1, 2] for the observation of cosmic rays with energy above the so-called Greisen-Zatsepin-Kuzmin (GZK) cutoff, it has been later developed into the study of a new form of dark matter.

The concept of dark matter composed by superheavy particles with $m_X \gtrsim 10^{13}$ GeV (further on we shall call them X particles) at first glance seems to be exotic, mainly because of two questions: How can SHDM particles have a lifetime exceeding the age of the universe, and why their abundance should be dominant in the universe today? The answers to both questions have been known for a long time and are based on quite general theoretical concepts. The problem of the stability or the quasi-stability of a heavy particle exists also for the lightest supersymmetric particle, e.g. the neutralino. Discrete gauge symmetries protecting neutralinos from fast decays work equally well for other particles. A particular example of a particle with lifetime exceeding the age of the universe was given in Ref. [3]. The large abundance of superheavy relic particles can be provided by gravitational production [4], which works for superheavy particles very similar to the production of density fluctuations during inflation.

In contrast to usual thermal relics, like e.g. neutralinos, SHDM particles are non-thermal relics and have been never in chemical equilibrium with radiation. They must be produced very early, at the end of inflation. Then it is enough to transfer a tiny fraction from the energy of radiation to SHDM particles, less than 10^{-18} , in order to have $\Omega_X \sim 0.3$ now: The energy density of

non-relativistic X particles diminishes with time as $1/a^3$, where $a(t)$ is the scaling factor of the universe, while the energy density of radiation diminishes as $1/a^4$. When normalized at the inflationary epoch, $a_i = 1$, $a(t)$ has the enormous value $\sim 1 \times 10^{22}$ now. Not surprisingly, this small energy fraction can be transferred to X particles by many different mechanisms, such as thermal production at reheating [1, 5], the non-perturbative regime of a broad parametric resonance at preheating [6], and production by topological defects [1, 7].

Thermal production of X particles with $m_X \gtrsim 10^{13}$ GeV requires a very high reheating temperature T_{rh} . In supersymmetric cosmology, T_{rh} is limited by gravitino overproduction as $T_{\text{rh}} \lesssim (10^9 - 10^{10})$ GeV. However, the gravitino density can be diluted efficiently by entropy production during thermal inflation [8]. Thermal inflation solves the problem of overproduction of particle at reheating and allows higher temperatures with efficient SHDM production. In Ref. [7], it was shown that the maximal temperature after inflation can be much higher than T_{rh} .

X particles are efficiently produced at preheating [6]. This stage, predecessor of reheating, is caused by oscillations of the inflaton field after inflation near the minimum of its potential. Such an oscillating field can non-perturbatively (in the regime of a broad parametric resonance) produce intermediate bosons χ , which then decay into X particles. The mass of the X particles can be one or two orders of magnitude larger than the inflaton mass m_ϕ , which should be about 10^{13} GeV.

X particles can be also produced by topological defects, such as strings or textures. Particle production occurs at string intersections or in collapsing texture knots. X particles can also be produced by hybrid topological

defects, such as monopoles connected by strings or walls bound by strings. The main contribution to the X particle density is given by the earliest epochs, soon after topological defect formation. Topological defects of the energy scale $\eta > m_X$ can be formed in phase transitions at or slightly before the end of inflation. Efficient production of topological defects is predicted for the preheating stage.

However, the most remarkable creation mechanism for SHDM is its gravitational production [9]. Particles are created by time-variable gravitational fields during the expansion of the universe. For this mechanism the interaction of X particles with other particles (e.g. with the inflaton) is not required, even sterile particles are produced. The present abundance Ω_{shdm} of the X particles is mainly determined by its mass m_X , while the dependence of Ω_{shdm} on the reheating temperature T_{rh} is model-dependent. To provide $\Omega_{\text{shdm}} = 0.27$, needed according to WMAP observations [10], the mass of the X particle must be (a few) $\times 10^{13}$ GeV.

The stability of X particles can be ensured by discrete gauge symmetries. It must be weakly broken, if we want long-lived particles with lifetime $\tau_X \gtrsim t_0$, where t_0 is the age of the universe. This superweak symmetry breaking can occur due to wormhole [1] or instanton effects [2]. Alternatively, discrete gauge symmetries could be broken by higher-dimensional operators [11]. An example of a SHDM particle in a semi-realistic particle physics model are cryptons, i.e. bound-states from a strongly interacting hidden sector of string/M theory [3, 12, 13].

What are the prospects to observe SHDM, if X particles are absolutely stable?

This is a pessimistic case for SHDM, because unitarity limits severely the XX -annihilation cross section: Since the velocity of X particles is very small, $v \ll 1$, only the s-wave contributes to $\langle \sigma_{\text{ann}} v \rangle = a + bv^2 + \mathcal{O}(v^4)$, resulting in an unobservable small cross section, $\langle \sigma_{\text{ann}} v \rangle \approx a \lesssim 1/m_X^2$. An interesting and rather exceptional case was found in Ref. [14], when X particles are cosmologically produced in the form of close pairs and form bound states due to gauge interactions between them. The lifetime of pairs corresponds to the spiral-in time of pairs with their subsequent annihilation, as in the case of monopole-antimonopole pairs.

In the framework of gravitational production of SHDM, the mass of the X particle is fixed as (a few) $\times 10^{13}$ GeV, and we are left in the SHDM model with only one free parameter, the lifetime of the X particles τ_X . If one requires that the ‘‘AGASA excess’’ is explained by the SHDM model (see below), then this parameter is fixed by the UHECR flux observed by this experiment.

At present, the most interesting manifestation of SHDM may be the observations of UHECR beyond the GZK cutoff [1, 2, 15, 16, 17, 18, 19]. There are three basic signatures of UHECRs from SHDM:

- SHDM particles as any other DM particles cluster

gravitationally and accumulate in the halo of our galaxy with an overdensity 2.1×10^5 . Hence the UHECR flux from SHDM has no GZK cutoff in energy spectrum [1].

- Since in the decays or annihilations of X particles pions are more abundant than nucleons, UHE neutrinos and photons are the dominant component of the primary flux [1].
- The non-central position of the Sun in the galactic halo results in an anisotropic UHECR flux from SHDM [16].

The quantitative predictions for the energy spectra and the photon/nucleon (γ/N) ratio in the decays or annihilations of X particles required the extension of existing QCD calculations for parton cascades from the TeV scale up-to the scale m_X . The first calculations used the analytic limiting spectrum approximation [20] or extended the Monte Carlo simulation HERWIG [15]. More recent calculations using a SUSY-QCD Monte Carlo [21, 22] and the DGLAP evolution equations [22, 23, 24] predict quite accurately the secondary spectra from decays/annihilation of SHDM particles and agree well with each other. Their most important outcome for UHECR observations is the flat shape of the energy spectrum. At the relevant energies, it can be approximated as $dE/E^{1.9}$ while the photon/nucleon ratio is $\gamma/N = r_{\gamma/N}(x) \approx 2 - 3$ [22], being only weakly dependent on $x = 2E/m_X$.

An anisotropic UHECR flux from SHDM is guaranteed by the fact that the distance from the Sun to the outer boundary of the DM halo is largest in the direction of the galactic center (GC). Numerical simulations of the DM distribution show an increase of the DM density towards the GC as $\propto r^{-1}$ [25] or $\propto r^{-1.5}$ [26]. This further enhances the expected anisotropy. The relevant calculations for this anisotropy were presented in Ref. [17]. Comparisons of the calculated anisotropy [18, 19] with existing data of the air-shower arrays on the northern hemisphere have revealed no contradiction between data and model predictions. By contrast, detectors on the southern hemisphere able to observe the GC are much more sensitive to this anisotropy. The data of the old SUGAR detector located in Australia are only marginally consistent with the prediction of the SHDM model [27].

At what energy UHECRs from SHDM become the dominant component?

The answer to this question became unambiguous after the precise calculation of the spectrum of secondary particles produced in the SUSY-QCD cascade, which can be approximated as $\propto E^{-1.9}$. This spectrum is very flat and fitting it to the AGASA data [28] shows that it can become the dominant component of the UHECR flux only at energies above 8×10^{19} eV (see Fig. 1). This is an important and reliable conclusion about the status of UHECR from SHDM.

The photon dominance is another reliable prediction of the SHDM model. Note that this test is relevant mainly

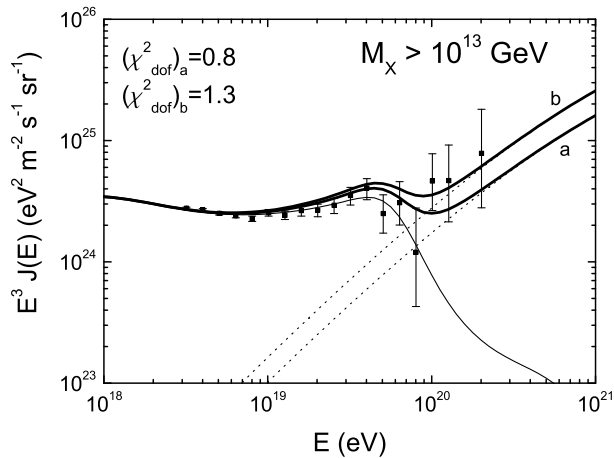


FIG. 1: The calculated spectrum of UHECRs from SHDM (dotted curves) in comparison with the AGASA data (from Ref. [22]). The spectrum from SHDM decays can explain only the highest energy events (“AGASA excess”). The dashed curve gives the universal spectrum of extragalactic protons [29]. The sum of these two spectra is shown by full curves for two SHDM fluxes with different normalizations. The χ^2 values are given for the comparison of these curves with the experimental data at $E \geq 4 \times 10^{19}$ eV. One can see that the SHDM flux can dominate only at energy higher than 8×10^{19} eV.

for energies higher than 8×10^{19} eV, where UHECRs from SHDM dominate the flux. Proton and photon induced showers can be distinguished by the muon component observed at ground level. An analysis of events with energies $E \geq 1 \times 10^{20}$ eV has been performed for the AGASA data [30, 31] and very recently in Ref. [32] for the combined AGASA [28] and Yakutsk data [33]. We shall discuss this analysis in Section 2. Here we only note that no photon induced showers have been found among six AGASA and four Yakutsk events with energies higher than 1×10^{20} eV. One may conclude therefore that the SHDM model is not confirmed by this analysis.

We summarize our introduction emphasizing that at present only the “AGASA excess” at $E \gtrsim 1 \times 10^{20}$ eV motivates the SHDM model as explanation for the existing UHECR data. The data of other detectors, e.g. Yakutsk or HiRes, are compatible with the GZK cutoff. In this case, the UHECR flux from SHDM can be only subdominant and is reduced compared to the fit to the AGASA data shown in Fig. 1. If the Auger experiment confirms the “AGASA excess”, the status of this model will be changed. Even in this case, the Auger detector has the great potential to confirm or to reject the SHDM model for UHECRs by testing its clearest signature, the anisotropy towards the galactic center.

One must clearly emphasize the following.

The observations of UHECR cannot exclude SHDM as explanation for the dark matter in the universe and in our galaxy. Assuming that the SHDM are gravitationally produced, the mass of the X particles is fixed and the

only free parameter of the SHDM model is the life-time τ_X . The “AGASA excess” fixes this parameter as $\tau_X \approx 10^{20}$ years.

From the HiRes, Fly’s Eye and Yakutsk data, that are compatible with the GZK cutoff, only a lower bound on τ_X can be derived. Within this lower bound, SHDM may still provide subdominant, but observable effects in UHECR observations, and some of the showers observed at the highest energies could be induced by secondaries from X decays. Thus the search for photons coming from directions close to the galactic center remains an interesting task for the Auger detector, even if the “AGASA excess” will be not confirmed.

The discussion above determines the strategy of this paper. In Section II, we obtain more accurately than in our previous work [22] the ratio γ/N for the SHDM model. Note, that the nucleon flux at $E \lesssim 1 \times 10^{20}$ eV is given mostly by extragalactic protons and thus our prediction is determined by the AGASA excess (see Fig. 1) and valid only for the AGASA data. We compare our prediction with existing analyses of the γ/p ratio using the AGASA data. The Yakutsk or HiRes data require a larger value for τ_X due to their agreement with the GZK cutoff and thus the γ/p ratio derived for the AGASA data is in this case an *upper limit*, not a prediction. In Section 3, we calculate the anisotropy of UHECRs from SHDM relevant for Auger observations, before we conclude.

II. RESTRICTIONS FROM PHOTON-INDUCED SHOWERS

In Ref. [22] we have calculated the ratio $r_{\gamma/N}(x)$ of photons to nucleons in the QCD cascade initiated by the decay of a X particle as function of $x = 2E/m_X$. Here we shall compute $\varepsilon_\gamma(E) = (\gamma/\text{tot})_E$ as the ratio of photon-induced showers to the total number of showers at the measured energy E using the following set of equations,

$$\varepsilon_\gamma(E) = \frac{J_\gamma^{\text{shdm}}(\lambda E)}{J_p^{\text{shdm}}(E) + J_p^{\text{extr}}(E) + J_\gamma^{\text{shdm}}(\lambda E)}, \quad (1)$$

$$J_\gamma^{\text{shdm}}(\lambda E) + J_p^{\text{shdm}}(E) + J_p^{\text{extr}}(E) = J_{\text{AGASA}}(E), \quad (2)$$

$$J_\gamma^{\text{shdm}}(E)/J_p^{\text{shdm}}(E) = r_{\gamma/N}(x), \quad (3)$$

where the diffuse fluxes $J(E)$ with indices ‘shdm’ and ‘extr’ refer to SHDM and extragalactic fluxes, respectively. The SHDM fluxes are taken as average over the galactic directions observed by AGASA. As extragalactic proton flux we use the universal spectrum from Ref. [29] as shown in Fig. 1. The SHDM spectra $J_\gamma^{\text{shdm}}(E)$ and $J_p^{\text{shdm}}(E)$ are taken from Ref. [22] (not using the power-law approximation). The photon flux J_γ is evaluated at the energy λE , where E is the energy determined experimentally assuming that the primary is a proton. The coefficient λ takes into account the differences in the shower

development between showers initiated by protons and by photons. These differences are caused mainly by the Landau-Pomeranchuk-Migdal effect.

Equation (2) normalizes the total flux at $E \gtrsim 1 \times 10^{20}$ eV to the observed “AGASA excess” (see Fig. 1).

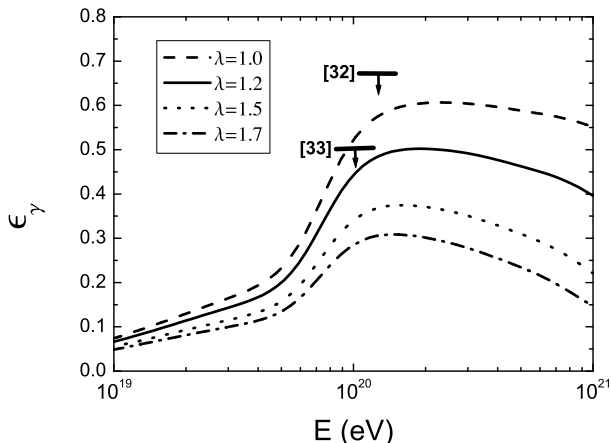


FIG. 2: Predicted ratio ε_γ as function of the observed energy for $m_X = 1 \times 10^{13}$ GeV and for different values of the λ parameter. The solid curve corresponds to $\lambda = 1.2$, valid according to Ref. [30, 31] for the AGASA site. The two limits in the figure are those obtained in [31] ($\varepsilon = 0.67$) and in [32] ($\varepsilon = 0.50$) from an analysis of the AGASA data.

The predicted ratio (1) is shown in Fig. 2 as function of the observed energy E for $m_X = 1 \times 10^{13}$ GeV and for various values of λ . This factor depends both on the local geomagnetic field and the detector type and varies therefore from experiment to experiment. In Refs. [30, 31], the effective λ was estimated as 1.2 – 1.3 for the AGASA site, while Ref. [34] estimated $\lambda = 2$ for AUGER.

The analysis of AGASA data at $E \geq 1 \times 10^{20}$ eV resulted in the following upper limits: $\varepsilon_\gamma < 0.67$ at $E \geq 1.25 \times 10^{20}$ eV at 95% CL in Ref. [31] and $\varepsilon_\gamma < 0.5$ at $E \geq 1.0 \times 10^{20}$ eV at 95% CL in Ref. [32].

Three remarks are in order.

- The energy calibration of different experiments by the position of the dip in the energy spectrum [35] requires a shift of the AGASA energies by the factor 0.9 and of the HiRes energies by the factor 1.2. These shifts lead to a very good agreement of the AGASA and the HiRes data. Such a shift decreases further the tension between our prediction of ε_γ and the upper limits from Ref. [31, 32].
- From the Yakutsk and HiRes data we cannot obtain a prediction for the γ/p ratio within the SHDM model, instead we obtain only an upper limit. These data agree with the GZK cutoff and can result only in the lower limit on τ_X , and thus in the upper limit on the UHE photon flux from SHDM. On the other hand, J_{extr} is fixed independently, and thus our calculations give only an upper limit on

γ/p , which is lower than the curves in Fig. 2 obtained using the AGASA data.

- Is it possible to use the combined AGASA and Yakutsk data for the γ/p ratio as constraint on the SHDM model for UHECRs? Such a combination is possible but requires additional assumptions how this combination is performed. One possibility is to determine the true UHECR flux averaging appropriately the AGASA and Yakutsk data. Then the SHDM flux would be lower than the one shown in Fig. 1. Consequently, the predicted γ/p ratio would be also reduced, but could now be compared with the limit $\gamma/p \leq 0.36$ from the combined AGASA-Yakutsk data [32]. Another way to include the Yakutsk data in our analysis is to assume that the lower flux measured by Yakutsk is caused by a statistical fluctuation. This assumption raises the question of the compatibility of the measured AGASA and Yakutsk fluxes. The fluxes of the two experiments are already incompatible at lower energies, $10^{19} - 10^{20}$ eV, where the event numbers are high. Thus their difference cannot be explained simply by statistical fluctuations. Normalization by the dip [35] results in an energy shift of the AGASA and Yakutsk energies by a factor 0.9 and 0.75, respectively. After this procedure the fluxes coincide perfectly. This implies that the energies of two Yakutsk events are considerably below 1×10^{20} , and hence the upper limit γ/p increases compared to the one given in Ref. [32].

We thus conclude that the obtained upper limits on ε_γ (see Fig. 2) do not exclude, but disfavor the SHDM model as explanation for the UHECRs.

III. ANISOTROPY

The anisotropy in the direction to the GC is the most reliable prediction of the SHDM model. Here we shall present the detailed calculations of this anisotropy in the form convenient for an analysis of the Auger data.

The angular dependence of the UHECR flux from SHDM is given by

$$J_{\text{shdm}}(\theta) = \frac{1}{4\pi} \int_0^{r_{\text{max}}(\theta)} dr \dot{n}_X(R), \quad (4)$$

where r and R are the distances from the Sun and the GC, respectively, and \dot{n}_X is the rate of X particle decays given by $n_X(R)/\tau_X$. As distributions of the DM in the galactic halo we use the NFW [25] and Moore *et al.* [26] profiles,

$$n_X(R) = \frac{n_0}{(R/R_s)^\alpha (1 + R/R_s)^{3-\alpha}}, \quad (5)$$

with $\alpha = 1$ and 1.5 for the NFW and Moore *et al.* profile, respectively. We use $R_s = 45$ kpc as obtained in Ref. [18].

The distance to the boundary of halo in the direction θ is given by

$$r_{\max}(\theta) = r_{\odot} \cos \theta + \sqrt{R_h^2 - r_{\odot}^2 \sin^2 \theta}, \quad (6)$$

Changing variable $r \rightarrow R$ in the integral of Eq. (4) we obtain as convenient formula for numerical computations

$$J_{\text{shdm}}(\theta) = \frac{1}{4\pi\tau_X} \left[2 \int_{r_{\odot} \sin \theta}^{r_{\odot}} dR R \frac{n_X(R)}{\sqrt{R^2 - r_{\odot}^2 \sin^2 \theta}} + \int_{r_{\odot}}^{R_h} dR R \frac{n_X(R)}{\sqrt{R^2 - r_{\odot}^2 \sin^2 \theta}} \right]. \quad (7)$$

We define the anisotropy A as the ratio of the flux in the direction of the GC within the solid angle Ω to the flux at the same energy in the perpendicular direction,

$$A(\theta, E) = \frac{J_{\gamma}^{\text{shdm}}(\leq \theta, \lambda E) + J_p^{\text{shdm}}(\leq \theta, E) + J_{\text{extr}}(E)\Omega(\theta)}{[J_{\gamma}^{\text{shdm}}(90^\circ, \lambda E) + J_p^{\text{shdm}}(90^\circ, E) + J_{\text{extr}}(E)]\Omega(\theta)}. \quad (8)$$

Here, $J_{\text{shdm}}(\leq \theta)$ is the SHDM flux within the angle θ relative to the direction to the GC, i.e. within the solid angle $\Omega(\theta) = 2\pi(1 - \cos \theta)$, and J_{extr} is the extragalactic proton flux taken at the same energy as J_p^{shdm} . Explicitly, the angular dependence of the fluxes of Eq. (8) is given by

$$J_{\text{shdm}}(\leq \theta) = \int_0^\theta 2\pi \sin \theta d\theta J_{\text{shdm}}(\theta), \quad (9)$$

$$J_{\text{shdm}}(90^\circ) = \frac{1}{4\pi\tau_X} \int_{r_{\odot}}^{R_h} dR R \frac{n_X(R)}{\sqrt{R^2 - r_{\odot}^2}}. \quad (10)$$

The normalized energy-dependent flux J_{shdm} in Eq. (7) is obtained by normalization to AGASA excess according to Eq. (2) at $E \geq 1 \times 10^{20}$ eV.

Graphical results of our numerical computations for $m_X = 1 \times 10^{13}$ GeV are presented in Fig. 3 for the NFW and Moore *et al.* profiles, while in the Tables I and II numerical values of the anisotropy are given for small θ and different energies. The anisotropy $A(\theta, E)$ weakly depends on λ and is maximized for small θ , but the need for a sufficient number of events will make the choice of an intermediate value of θ more suitable.

IV. CONCLUSIONS

Superheavy particles are an interesting candidate for the dark matter in the universe. They are naturally produced in the expanding universe via gravitational interactions, when the Hubble parameter $H(t)$ exceeds their mass, $H(t) \gtrsim m_X$. The observed density of DM, $\Omega_m = 0.27$, determines the mass of the particle as $m_X \sim (\text{a few}) \times 10^{13}$ GeV. This makes SHDM a natural candidate for the production of UHECR.

where $R_h = 100$ kpc is the size of the DM halo and $r_{\odot} = 8.5$ kpc the distance of the Sun to the GC.

TABLE I: Numerical values of $A(\theta, E)$ in the case of the NFW DM density profile.

E — θ	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°
1 EeV	1.03	1.03	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.01
10 EeV	1.73	1.62	1.56	1.51	1.48	1.45	1.43	1.41	1.39	1.37
30 EeV	2.64	2.40	2.26	2.16	2.08	2.02	1.96	1.92	1.87	1.84
60 EeV	3.96	3.52	3.26	3.08	2.94	2.83	2.73	2.65	2.57	2.51
100 EeV	6.42	5.62	5.15	4.82	4.56	4.35	4.17	4.02	3.89	3.76

TABLE II: Numerical values of $A(\theta, E)$ in the case of the Moore DM density profile.

E — θ	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°
1 EeV	1.17	1.11	1.09	1.08	1.07	1.06	1.05	1.05	1.04	1.04
10 EeV	5.08	3.75	3.16	2.81	2.57	2.40	2.26	2.15	2.06	1.99
30 EeV	10.3	7.2	5.90	5.11	4.57	4.17	3.86	3.61	3.41	3.24
60 EeV	17.8	12.3	9.88	8.45	7.47	6.75	6.19	5.74	5.37	5.05
100 EeV	32.1	22.0	17.5	14.8	13.0	11.7	10.6	9.80	9.11	8.53

The SHDM particles (X particles) can be stable (due to, e.g., a discrete gauge symmetry) or quasi-stable (due to super-weak discrete gauge symmetry breaking). The energy spectrum of produced particles is approximately a power-law, $\propto E^{-1.9}$. The dominant primary particles are neutrinos and photons. The only free parameter of the SHDM model as explanation of the “AGASA excess” is the lifetime of the X particles, which is determined from the UHECR flux as observed by AGASA as $\tau_X \approx 10^{20}$ years.

SHDM is accumulated in the halo of our galaxy with an overdensity of 2.1×10^5 and the produced UHECR flux thus do not has a GZK cutoff. The production spectrum

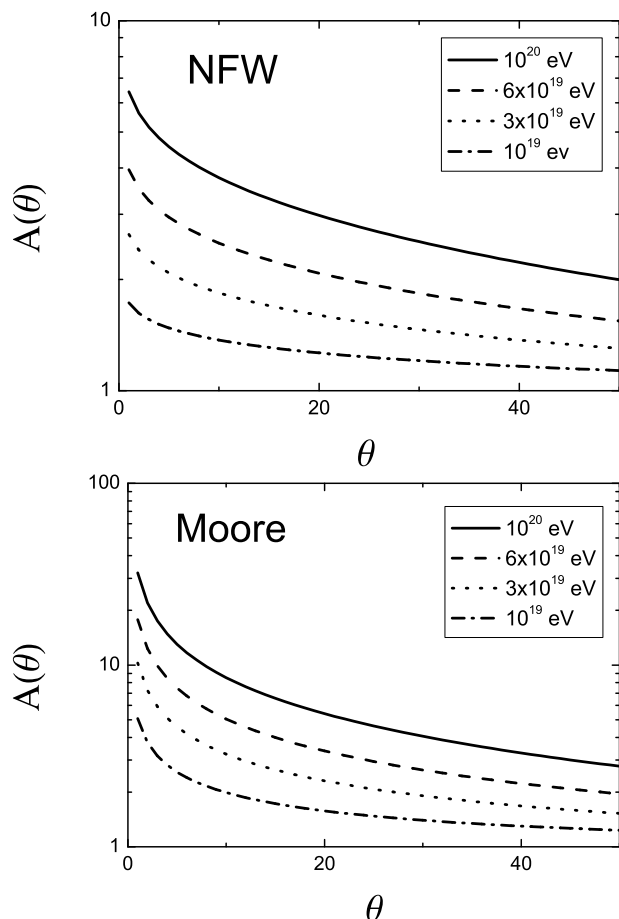


FIG. 3: Anisotropy $A(\theta, E)$ as defined by Eq. (8) for the NFW density profile (top) and the Moore density profile (bottom); in both cases $\lambda = 2.0$ is used appropriate for the surface detectors of Auger [34].

$\propto E^{-1.9}$ can explain only the “AGASA excess” at $E \gtrsim 8 \times 10^{19}$ eV. The two other signatures of this model are

the dominance of photons and the anisotropy towards the galactic center.

SHDM as a model for UHECR is at present disfavored by the following points:

- The “AGASA excess” is not confirmed by the HiRes, Fly’s Eye and Yakutsk data, although the statistics of all these three experiments is too low to state a serious contradiction. The “AGASA excess” can be a combined effect of a small systematic error in the energy determination and of the low statistics [35, 36].
- Among 17 events with energy $E \gtrsim 1 \times 10^{20}$ eV detected by all arrays, there is not a single event established as a gamma-induced air shower.

In this paper we calculated the anisotropy, which can be reliably tested by the future data of the Auger experiment.

The SHDM model has been tuned to explain the “AGASA excess”. If this excess is not confirmed, or the predicted anisotropy is not found, it will not exclude SHDM as explanation of the DM in the universe. Excluding SHDM as explanation of the observed UHECRs will put only a lower limit on τ_X . The production of UHE photons and neutrinos by DM in the halo as a subdominant (for the observed UHECR) effect will remain a signature of this model.

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